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Compact WLAN notched ultra-wideband band pass filter

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This paper has investigated WLAN notched Ultra-Wide Band (UWB) Band Pass Filter with a wide upper stop band. The proposed design has folded half-wave line that has been incorporated in between slot line resonators. Designed UWB band pass filter has 3-dB cut-off frequencies at 3.2 GHz and 10.1 GHz with a notched band from 5.1 GHz to 5.4 GHz. Return loss and insertion loss in the first pass band have been greater than 12 dB and less than 1.5 dB. These have been greater than 25 dB and lesser than 1.8 dB in the second pass band. In the upper transition edge, an introduced filter has accomplished pointed roll-off with attenuation of 62 dB, wide stop band with the rejection of 20 dB till 12 GHz, and greater than 17 dB from 12 GHz to 18 GHz. Higher-order harmonics have been suppressed through quarter wavelength open stubs. The overall size of the filter is 27 x 9 x 0.8 mm3.

Keywords: Half wave line, Harmonic suppression, Microwave filter, Microstrip, Wide stop band

1 Introduction

The U.S. Federal Communications Commission (FCC) has considered Ultra-wideband frequencies from 3.1 GHz to 10.6 GHz as an unlicensed band since February 2002. Nowadays, UWB has been receiving greater attention in the research community due to its advantages such as high data rate, low power, minimized hardware, and low cost. UWB spectrum has been widely used in different applications such as Medical Monitoring, Imaging, and RADAR. But, UWB technology also has some limitations. One of the significant problems with the UWB Technology has been the interferences due to the co-existence of a few other commercial applications within the UWB spectrum, such as WiMAX and WLAN. UWB bandpass filters play a significant role in rejecting unwanted signals and selecting exact ultra-wideband frequencies. Many UWB bandpass filter characteristics have been enhanced by using multimode resonators, modified slot resonators, hairpin resonators, or stub-loaded ring resonators1-3. Despite that, to avoid interferences, for UWB applications, a UWB filter with a notched band is appropriate. Some of the UWB bandpass filters with band notch characteristics have been reported. UWB bandpass filter with notch characteristics has been explored with different techniques such as composite right/left-handed (CRLH) transmission lines. Stub-loaded stepped impedance resonator, C-shaped resonator with the defected ground, slot line microstrip resonator with defected base, and exponentially tapered impedance line stub loaded microstrip resonator4-8. For good performance in the passband, however, those designs have poor rejection in the stopband. UWB bandpass filter with a notch has been designed using resonators and DGS9-15, which exhibits good rejection in stop band at the cost of design complexity. Designs using dual stepped-impedance stub-loaded resonators have good passband and out-of-band performance but require a larger size16. The design of the UWB bandpass filter, which has good passband response, better attenuation in the transition region, broad upper stopband rejection within a simple method for easy fabrication, remains a challenge. Hence, this work has explored the structure of UWB BPF using two folded half-wave lines incorporated between slot line resonators and also includes four open stubs. Compared to existing BPFs, the proposed technique is simple. The proposed BPF has a wide upper stopband, six Transmission Zeros, and band-edge attenuation of 62dB

2 Materials and Methods

Using HFSS, the proposed UWB band pass filter was made on the FR-4 substrate having a loss tangent of 0.02, thickness of 0.8 mm and a dielectric constant

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(ε_r) of 4.4. Design of the proposed UWB band pass filter comprised two band pass filters with different center frequencies. These two band pass filter were designed by using folded half wave line incorporated between slot line resonators. Two arms of the folded half wave lines were tightly parallel coupled to the slot line resonator, formed as the coupled lines, to obtain a strong coupling for achieving a wideband response. Figure 1 shows the block diagram representation of the proposed filter.

The effective dielectric constant of microstrip was calculated using the Eq. (1)[17].

$$\varepsilon_{re} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left\{\left(1+12\frac{h}{W}\right)^{-0.5} + 0.04\left(1+12\frac{h}{W}\right)^2\right\} \quad \ldots (1)$$

The guide wavelength was calculated by Eq. (2) and basic structure of the filter was designed using folded half wave line incorporated in between slot line resonator as shown in Fig. 2. Parametric analyses were also carried out for finalizing the half wave length. The resonant frequencies were identified based on the group delay plot given in Fig. 3.

$$\lambda g = \frac{c}{f\sqrt{\varepsilon_{re}}} \quad \ldots (2)$$

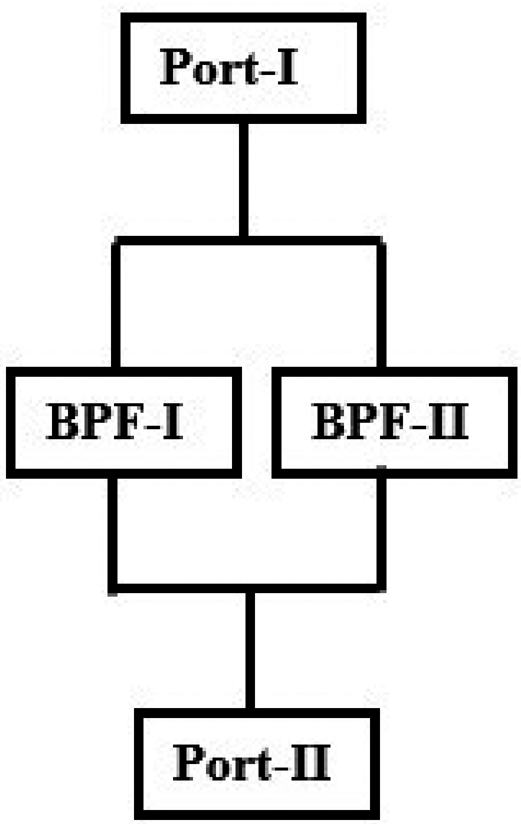

Fig. 1 — Block diagram of proposed filter.

The physical length of folded half wave line was determined as $\lambda g/2$.

The External Quality factor was computed by

$$Q_e = \frac{\omega_0}{\Delta\omega_{\pm 90}} \quad \ldots (3)$$

2.1 Band pass filter-I

It (BPF-I) was designed using folded half wave line incorporated in between slot line resonator, with the centre frequency of 8 GHz. This filter is responsible for the pass band from 6 GHz to 10.1 GHz. The dimension of L_1 was 11.92 mm. The 3-dB cut off frequencies were 6 GHz and 10.1 GHz, return loss was better than 12 dB and insertion loss was 1.5 dB. The layout and simulated results of BPF-I are given in Figs 4 & 5 respectively.

2.2 Band pass filter-II

It was designed using folded half wave line incorporated in between slot line resonator, with the center frequency of 4 GHz. This filter was responsible for the pass band from 3 GHz to 5 GHz. The dimension of L_2 was 21.83 mm. The 3-dB cut off frequencies were 3 GHz and 5 GHz, return loss was better than 12 dB and insertion loss was 1.5 dB. The

Fig. 2 — Half-wave line filter structure.

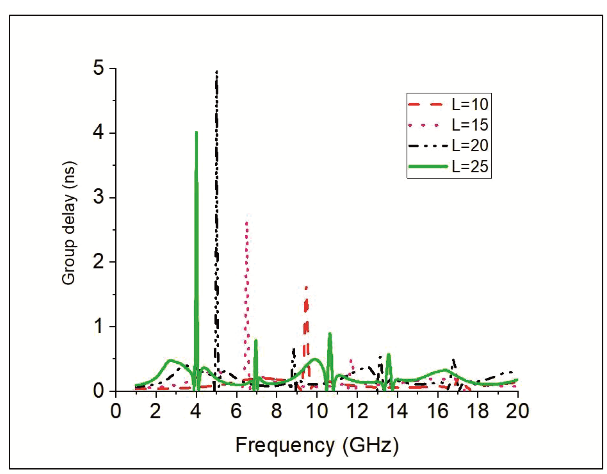

Fig. 3 — Resonant frequencies with different length.

layout and simulated results of BPF-II are given in Figs 6 and 7 respectively. Parametric analyses were carried out for the gap between input line and folded half wave line then gap dimension was optimized.

2.3 Proposed UWB band pass filter

By combining BPF-I and BPF-II, Ultra-wideband response was attained from 3.2 GHz to 10.6 GHz with notch band at the center frequency of 5.2 GHz. The layout and simulated results of combined BPF-I & II are given in Figs 8 & 9 respectively.

From Fig. 7, it was clear that harmonic mode occurs at 7.8 GHz, by proper coupling, it was combined with resonant mode of BPF-I to achieve a wide pass band. This can be viewed from Fig. 9. Poor stop band rejection was seen at 12 GHz which was due to higher order mode at that frequency. Open

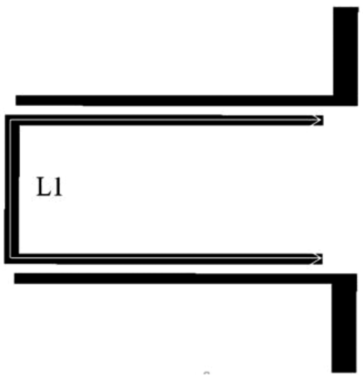

Fig. 4 — Layout of BPF-I.

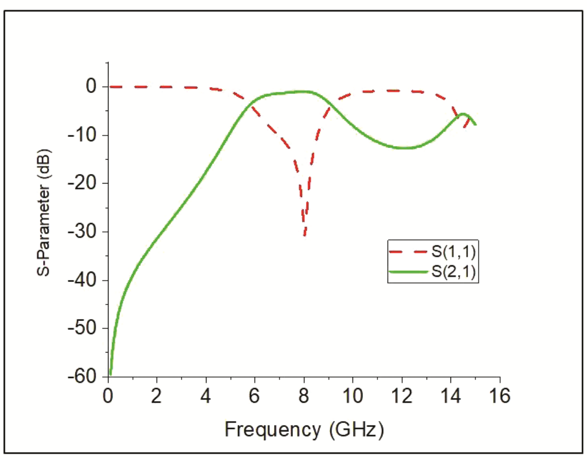

Fig. 5 — S-parameter plot –BPF-I.

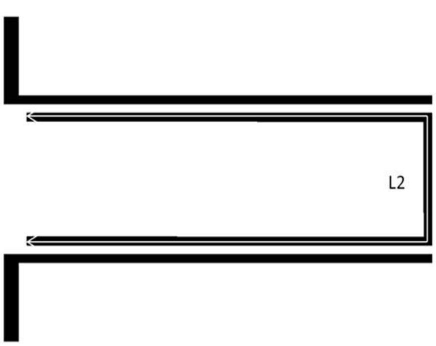

Fig. 6 — Layout of BPF-II.

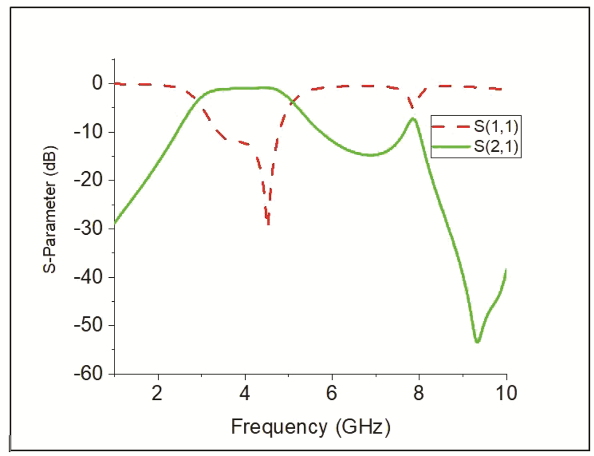

Fig. 7 — S-parameter plot –BPF-II.

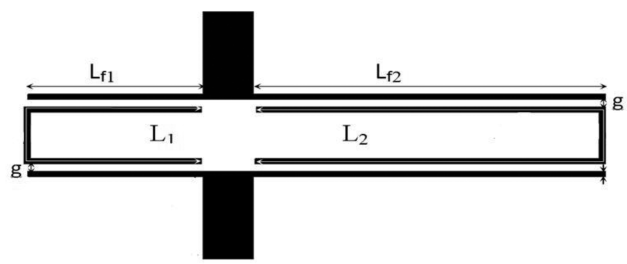

Fig. 8 — Layout of UWB BPF-A.

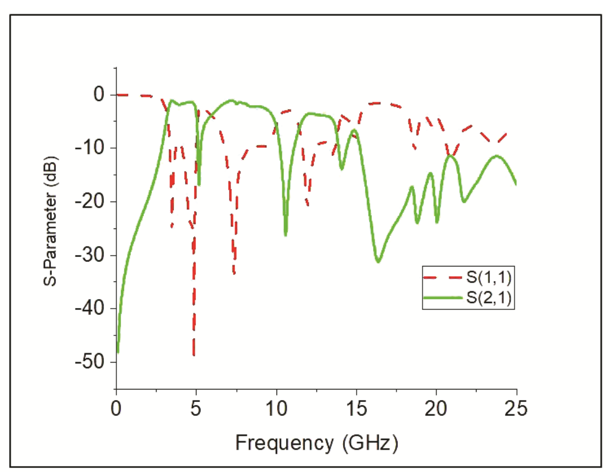

Fig. 9 — S-parameter plot –UWB BPF-A.

stubs could be included to eliminate higher order modes[18]. Hence, two quarter wavelength open stubs were included on both sides of the filter as shown in Fig. 10 and named as UWB BPF-B. The simulated result of UWB BPF-B is shown in Fig. 11.

Yet, the rejection in the stop was not as effective as required. Hence, it was decided to propose two more quarter wave length open stubs in the filter symmetrically on the other side as shown in Fig. 12 and named as UWB-BPF-C. The simulated results are shown in Fig. 13.

This shows high band-edge attenuation and wide stop band with good rejection of out of band frequencies. The performance comparison of UWB BPF-A, BPF-B and BPF-Care given in Table 1 and it was obvious that UWB BPF-C with four open stubs accomplished wide stop band with better rejection and had a very good harmonic suppression. Group delay of the filter was less than 0.5 ns in the pass band. This is shown Fig. 14.

The Physical dimensions of the proposed filter are given in Table 2. Approximate lumped equivalent circuit was realized for the proposed UWB BPF-C. That is given in Fig. 15.

The input admittance of equivalent circuit is derived and given in Eqs. (4 & 5), where Y_{in1} and Y_{in2} represented input admittances of the left and the right-side symmetry of the proposed design[19].

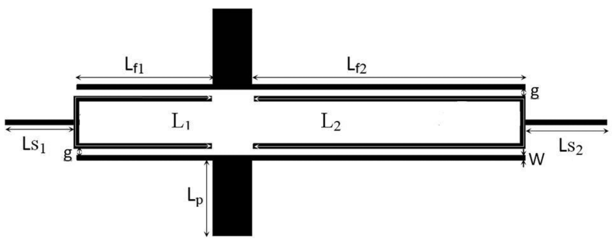

Fig. 10 — Layout of UWB BPF-B.

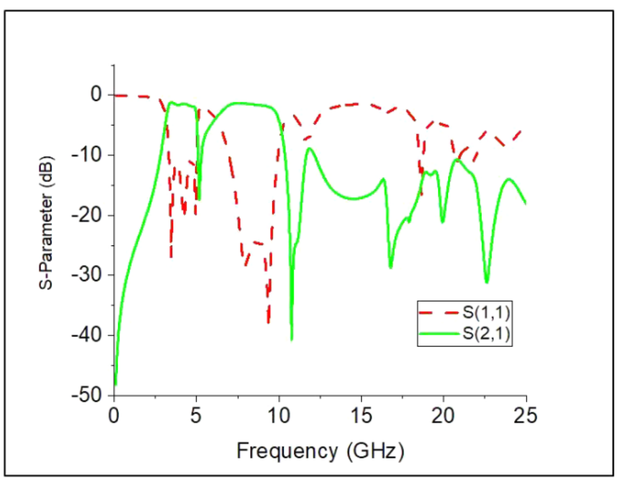

Fig. 11 — S-parameter –UWB BPF-B.

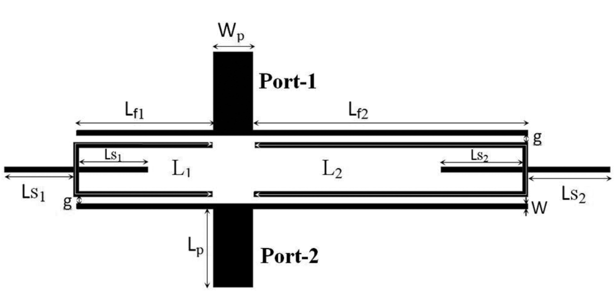

Fig. 12 — Layout of UWB BPF-C.

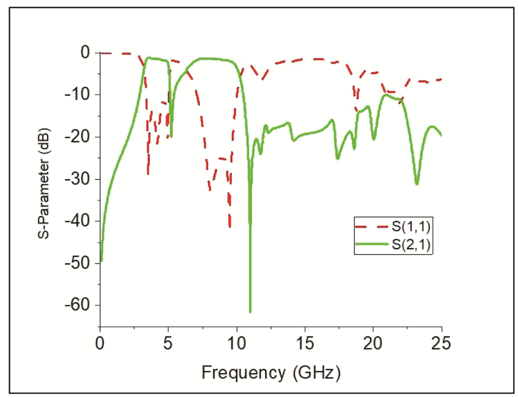

Fig. 13 — S-Parameter –UWB BPF-C.

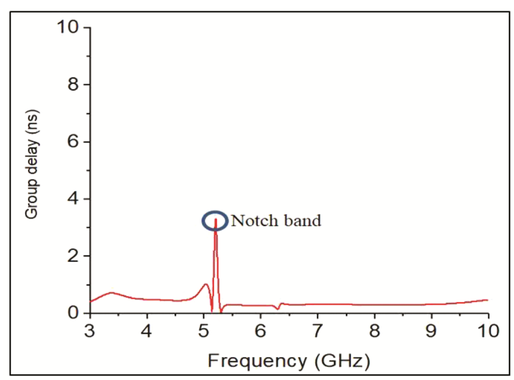

Fig. 14 — Group delay plot of the proposed filter

Table 1 — Performance comparison of UWB BPF-A, BPF-B & BPF-C

Filters	I.L. (dB)	R.L. (dB)	P.E.A. (dB)	TZs	Stop band rejection (dB)	F.H.H.S. (dB)
UWB BPF-A	1.8	> 10	28	6	> 4	4
UWB BPF-B	1.8	> 11	40	4	> 10	10
UWB BPF-C	1.8	> 12	62	6	> 16	20

I.L.: Insertion Loss; R.L.: Return Loss; P.E.A.: Pass band Edge Attenuation; TZs: Transmission Zeros; F.H.H.S.: First Higher Order Harmonic Suppression.

$$Y_{in1} = \frac{G_1\omega L_1 L_{S1} + j(\omega^2 L_1 L_{S1}(C_{m1}+C_{o1}+C_{o2}+C_1) - (L_{S1}+L_1))}{\omega L_1 L_{S1}} \quad \dots (4)$$

$$Y_{in2} = \frac{G_2\omega L_2 L_{S2} + j\left(\omega^2 L_2 L_{S2}(C_{m2}+C_{o3}+C_{o4}+C_2) - (L_{S2}+L_2)\right)}{\omega L_2 L_{S2}} \quad \dots (5)$$

At resonance $Y_{in1} = -Y_{in2}$

3 Results and Discussion

The proposed UWB band pass filter was made on FR4 substrate having a loss tangent of 0.02, thickness of 0.8 mm and a dielectric constant (ε_r) of 4.4 using High Frequency Structure Simulator (HFSS) and the same was fabricated. Figure 16 shows the fabricated prototype of the proposed UWB BPF-C. The overall size of the filter was 27 x 9 x 0.8 mm^3. For the proposed BPF-C, the simulated responses are plotted in Fig. 14. The simulated response showed that 1±0.5 dB insertion loss, better than 12 dB return loss and 1.5±0.5 dB insertion loss, better than 25 dB return loss in the pass bands of 3.2 GHz to 5 GHz and 6.5 GHz to 10.1 GHz respectively. With maximum 20 dB rejection at 5.2 GHz, the filter rejected the WLAN signals from 5.1 GHz to 5.4 GHz. Proposed filter also accomplished 20 dB stop band rejection till 11.5 GHz, 62 dB attenuation in the upper pass band edge, 103.7 % FBW, better than 16 dB rejection from 11.5 GHz to 19 GHz and 10 dB from 19 GHZ to 25 GHz. Six transmission zeros appeared at 10.98 GHz, 11.96 GHz, 17.4 GHz, 18.6 GHz, 20 GHz and 23.2 GHz. The performance comparisons of the proposed BPF with the existing filters are given in Table 3. From

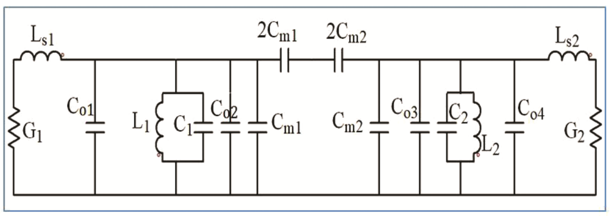

Fig. 15 — Equivalent circuit of the proposed filter[19].

Table 2 — Physical dimensions of the proposed filter

Parameters	Dimension (mm)
L_{f1}	5.35
L_{f2}	10.75
L_{s1}	2.7
L_{s2}	3.2
L_1	12.92
L_2	22.83
g	0.25
W	0.2
L_p	3
Wp	1.56

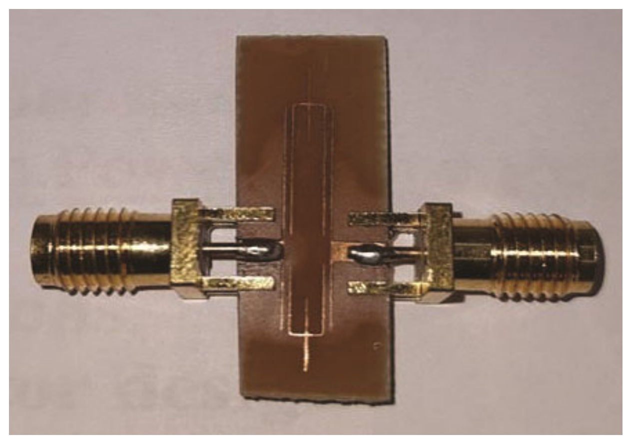

Fig. 16 — Photograph of fabricated filter.

Table 3 — Comparison between the proposed UWB Band pass filter and other works[4,5,6,9,10,11,15,16,18]

Ref.	P.B.F. (GHz)	I.L. (dB)	R.L. (dB)	N.F. (GHz) /A(dB)	TZs	3-dB FBW (%)	S.B.W. (GHz)/ Rejection level(dB)	Size (mm^2)	Material/ε_r	G.D. (ns)
[4]	3.07 - 10.64	NA	>10	4,7/ 12	0	NA	14/ 6	8.78x2.4	FR4/4.4	NA
[5]	3.1 - 10.1	1.3/1.1	8/12	5.2	5	52/55	11/ >18	20x 10	RT.D./2.2	0.4
[6]	3.1 - 10.6	2.6	NA	5.8/NA	2	89.5-131.8	NA	20x5.7	FR4/4.4	< 0.2
[9]	2.9 - 10.9	0.7	>15	6/17	3	NA	16.5/15	NA	2.55	NA
[10]	3.1 - 11.02	1	NA	5	3	50.38	25/10	19.9x13.7	2.2	NA
[11]	3.8 - 10.1	< 2.5	>10	5.1/NA	NA	NA	15/10	55x20	RT.D/2.2	NA
[15]	2.85 - 11.3	1.7	> 10	5.2/ >15	2	6.21	18/ > 15.6	11.08 X 11.7	FR4/4.4	< 0.4
[16]	3.2 - 11.01	NA	10	5.7-6.3/NA	0	NA	NA	49.3x15	RT.D/2.2	0.5
[18]	3.4 - 10	2	10	5.2/22.7	2	100	19/ >12	32.3 X 13	RT.D/2.2	0.75
This work	3.2 - 10.1	< 2	>12	5.1 - 5.4 /20	6	103.7	19,25/16, 10	27 x 9	FR4/4.4	< 0.5

P.B.F.: Pass Band Frequency; I.L.: Insertion Loss; R.L.: Return Loss; N.F.: Notch Frequency; A: Attenuation; FBW: Fractional Band Width, S.B.W.: Stop Band Width; G.D.: Group Delay; RT.D.: RT Duroid, NA: not available in reference paper.

Table 3, it can be noted that the proposed filter was better in terms of compactness and out of band rejection level.

4 Conclusion

This paper has investigated UWB band pass filter with a wide upper stopband and notch band. The filter design uses two bandpass filters made by using two folded half-wave lines incorporated between slot line resonators. The filter has been made on the 0.8 mm thick FR4 substrate with a loss tangent of 0.02 and a dielectric constant (εr) of 4.4 using HFSS. The proposed filter has been fabricated, and its analysis is presented in the paper. The lumped equivalent circuit for the proposed filter has been drawn, and admittance equations have also been derived. The proposed work has been compared with other results, and it's been evident that the proposed UWB band pass filter has good performance, compact size, and wide upper stopband.

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